# LIQUID DEUTERIUM NEUTRON ATTENUATOR FOR BROAD-BAND PHOTON BEAM FACILITY†

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## Summary

The photo-production facility at Fermilab utilizes a two section liquid deuterium attenuator, 103 feet in length, to reduce the neutron flux and produce a pure high energy photon beam. The facility is located in the Proton East experimental hall. The facility also includes nine 10 foot long sweeping magnets. A unique refrigeration system[1,2] supplies mechanically refrigerated helium gas trace cooling to condense deuterium directly in a flask. The control system permits remote operation of the cryogenic system and also acts as an interface to the Proton Area operations computer. The computer can be used to monitor the operating parameters and for partial control of the system. The facility is presently in use as part of the Proton Area experimental program.

## Introduction

The Proton Area photon facility uses liquid deuterium to attenuate neutrons and provide the clean photon beam desired for photo-production experiments.

The upstream attenuator section is 35.5 feet long and contains 6 liquid liters of deuterium. The 67 foot downstream section contains 28 liters. The sections are seperate except for common vent and deuterium recovery systems and may be independently operated. The 67 foot section can be quickly emptied into a liquid reservoir for background runs or to utilize the unattenuated neutron beam.

The system is located in a shielded cave in the Proton East experimental hall. The concrete cave is 150 feet long, 13 feet wide and 10 feet high. The area is located 16 feet below ground level. This underground cave with limited ventilation and crowded conditions, combined with the 34 liter volume, dictated special safety considerations.

The attenuator system features six lines of defense, and when reviewed and tested, is as safe as is possible within the constraints of the experiments and the area.

The attenuator was designed and fabricated by the Cryogenics Group of the Research Service Department, who has overall responsibility for system operation. The Proton Department and the Cryogenics Group installed the system into the Proton Area.

## Description of System Components

### Magnet Assembly

The deuterium filter vacuum vessel is installed into the gap of a series of pitching magnets with horizontal fields as shown in Fig. 1. The upstream attenuator section is enclosed in three, 3 inch gap, 10 foot long magnets, the downstream section is enclosed in six, similar magnets with 3-1/2 inch gaps. The vacuum vessels fit into the magnets with 0.060 inch clearance. Vacuum vessel junction boxes occur between the magnets.

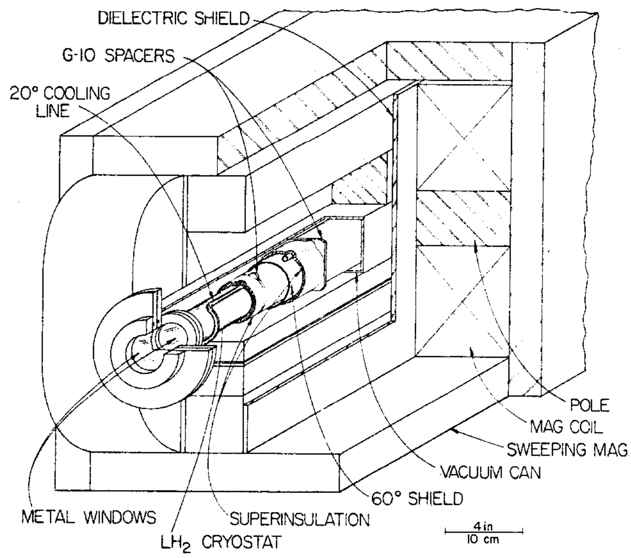


Fig. 1 Cutaway view of pitching magnet and attenuator cryostat.

The magnets are constructed to National Electrical Code Class I, Division 2 standards. Exposed buss bar area is minimized and is specially insulated to prevent electrical sparking. Each group of magnets is mounted on a box girder for stability and ease of alignment. If the magnet current is interrupted, the induced eddy currents in the cryostat are minimized by the large solid magnet core. If despite all of the safeguards, current from the magnet coil should arc to the vacuum vessel wall, the vacuum vessel should carry the full load current until the magnet is shut down.

### Attenuator Flasks and Heat Shields

The deuterium flasks are fabricated from tubing which is butt welded to form a continous tube of the desired length. Window flanges are welded on both ends of the flask tubes. Trace cooling tubes are soldered to the outer surface of the flasks. Closely fitting spacers made of G-10 fiberglass laminate support the flasks inside the heat shield. Ten layers of superinsulation is wound on the flask and fastened into place with two wraps of 0.005 inch Mylar.

* Operated by Universities Research Association Inc. Under Contract with the United States Energy Research and Development Administration.

The open, trace cooled heat shields are fabricated and supported in a similar manner.

The upstream flask OD is 1.125 inch with a 0.035 wall thickness, the shield OD is 1.750 inch with a 0.035 wall. The trace cooling tube OD is 0.312 inch with a 0.020 wall. All of the upstream section components are fabricated of 6061 aluminum. The flask has 0.005 inch aluminum end windows.

The downstream section has a flask OD of 0.750 inch (0.035 wall), a 2.750 inch OD heat shield (0.035 wall) and a 0.312 inch OD (0.020 wall) trace cooling tube. The entire downstream heat shield, flask and 0.005 inch end windows are fabricated of 304 stainless steel.

Downstream Reservoir

A stainless steel reservoir having a slightly larger volume than the flask is connected below the downstream attenuator. To empty the flask, the helium operated cold valve is opened to allow liquid to run into the reservoir by gravity. The cold valve remains open. Boil off from the reservoir is recondensed and flows back into the reservoir. To refill the flask, the cold valve is closed allowing the pressure to build in the reservoir forcing liquid from the reservoir into the flask until the reservoir siphon tube is exposed.

Attenuator Cryostats

Both cryostats are fabricated of 6061T6 square aluminum tubing. The upstream vessel is 3 x 3 inch, with a wall thickness of 0.187 inch; the downstream section is 3-1/2 x 3-1/2 inch and has a wall thickness of 0.156 inch. Cryostat sections are flanged to provide ease of assembly.

A low heat leak locating collar attached to the flask tube and heat shield positions both with respect to the cryostat. During cooldown, the collar prevents motion at the termination end of the assembly; all of the contraction is taken up by allowing the heat shield to slide within the cryostat and the flask to slide within the shield.

The junction boxes between cryostat sections are aluminum with Buna-N O-ring seals. The beam windows are constructed of 0.005 inch aluminum foil and are pressure tested to 125 psid. A rupture disk is located at each end of the cryostat and is connected to the emergency vent system.

Each rupture disk has a 2 inch diameter port and is equipped with an arrowhead piercing device. The arrowhead pierces the 0.010 inch Mylar diaphram at the slightest positive pressure, leaving the full port open for emergency venting.

Refrigerator

A 50 watt 20° K refrigerator is used for each section. The refrigerators are Philips Norelco, Model PGH-105 supplied by Cryogenic Technology Inc.

The basic engine - expander is powered by a 15 hp electric motor. Helium gas is used as the working refrigerant. Compression, cooling, expansion and regeneration phases are utilized to obtain refrigeration at two temperature levels. The 20° K stage supplies refrigeration to cool the flasks. The refrigeration is coupled to the flask wall by circulating 20° K helium gas through the trace cooling tubes. A small turbine provides 1 psid for this gas loop.

The 60° K stage is similarly coupled to a deuterium gas precooling heat exchanger. The remaining refrigeration in the 60° K loop is used to trace cool the heat shield before returning to the refrigerator.

The circulating gas is lead from the refrigerators to the cryostats through semi-flexible, vacuum insulated transfer lines.

Freon Cooler

The exhaust heat from the refrigerators is rejected to 5 ton air conditioning recondensers. The units are mounted outdoors to reject heat outside of the Proton East Hall. Copper lines are used to transfer the Freon coolant which is expanded directly into the water exchanger with a conventional expansion valve. Interlocks monitoring Freon flow and temperature, protect the refrigerator from malfunctions of the Freon system.

Instrumentation

Standard Fermilab hydrogen target control systems are used to control and monitor both filter sections. Readouts include, resistance type pressure transducers, vacuum thermocouple gauges, cold discharge ionization gauges and pressure gauges. Liquid levels are monitored with carbon resistors placed in the flasks and reservoir. Some of the readouts are used to interlock the control system.

Both control racks are connected to the Proton Area operations computer and can be operated remotely from the Proton Area control room.

Recovery System

The deuterium recovery system consists of 266 cubic feet of tank storage. The storage tank is connected statically as a buffer volume into the deuterium circuit at all times. A compressor is not used. The only deuterium lost from the system during routine operation is that used for initial purging and that remaining in the flask when the system is warmed to room temperature.

Safety Equipment

The nature of the Proton East cave presents some unique problems regarding use of explosive cryogens. The safety system includes window valves, enclosures around the cryostats, explosive gas detectors and alarms, in addition to externally vented pressure reliefs.

Each end of both attenuator sections is equipped with a remotely operated vacuum gate valve. The valves protect the cryostat windows and are open only when the experiment is taking beam. A sheet metal and fire retardant canvas enclosure is installed over the end of each section. The enclosures are force ventilated through a plenum to an outside exhaust stack. Several explosive gas detecting heads are placed in critical locations and control local and remote alarms.

The Proton hall is a high radiation area, access is therefore limited to "beam-off" conditions. Access is also controlled when the attenuator contains deuterium.

## System Schematic

Figure 2 shows the mechanical configeration of the cryogenic system.

## Operation

When the entire system has been checked for running status and the insulating vacuum established, the flasks are purged and then opened to the deuterium supply tanks. Initally the deuterium storage system contains 75 psia of deuterium gas.

The refrigerators are started; after 3 hours the upstream flask begins to condense deuterium at a rate of one liter per hour. It takes 5 hours to completely fill it after condensation begins. The downstream flask takes approximately 14 hours to reach condensing temperature and another 24 hours to completely fill it.

When each flask is full the fill valve is closed and the temperature controller is set to hold the deuterium flask pressure constant at one atmosphere. The temperature controller circuit monitors the vapor pressure and feeds back electrical heat into the trace cooling loops. The liquid deuterium density is therefore independent of variations in thermal load caused by fluctuations in the beam intensity, magnet temperature or ambient conditions.

When the attenuators are to be shut down, the refrigerators are stopped but the circulating fans left running. The system heat leak is used to empty the flasks. It takes approximately 6 hours to completely empty both sections. The attenuators are then pumped and back-filled with helium until the next operating period.

## Conclusions

The deuterium filter system as designed, fabricated and installed demonstrates the capability of mechanically refrigerated hydrogen/deuterium systems to operate safely and reliably in difficult environments while minimizing the hazards of flammable liquid cryogens.

At this writing the system has been operating semi-continuously for about six months for data taking runs. It has been warmed to ambient temperature between runs at least 10 times. The experimental results are reported elsewhere.[3]

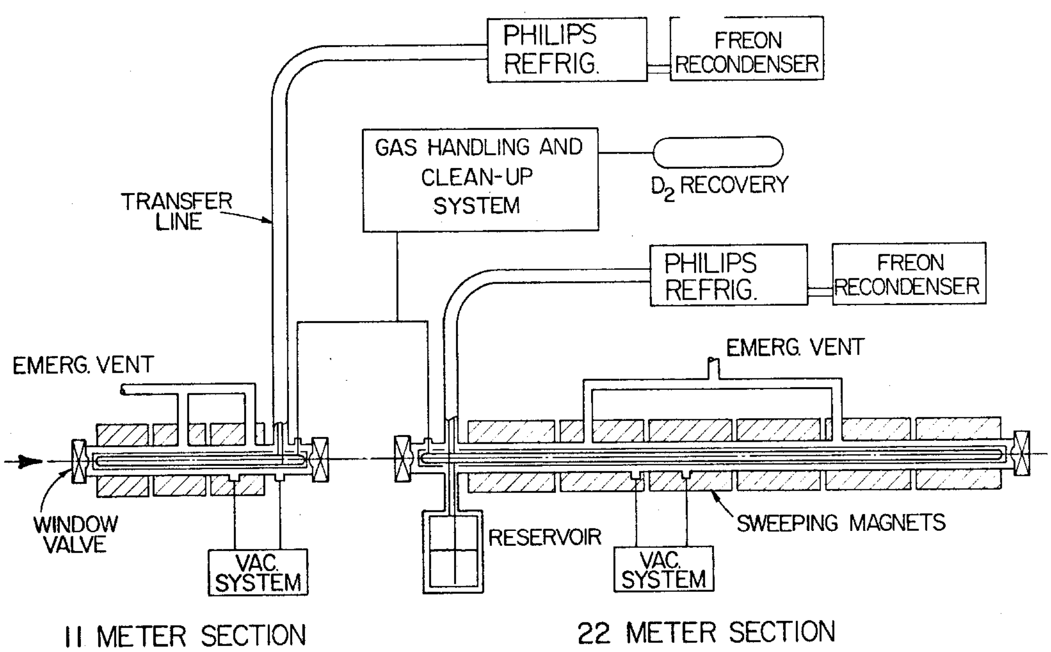


Fig. 2 Liquid deuterium attenuator.

## Acknowledgements

The authors wish to recognize and thank G. Smith, P. Yonker, C. Rodgers, R. Carra, E. Norton, D. Austin and J. Peifer of Research Services Cryogenics Group, Fermilab for their help in fabricating and installing the deuterium filter.

The authors also wish to acknowledge M. Binkley, R. Bailey, R. Bennett, R. Shovan, A. Guthke and R. Scherr of the Proton Department for their cooperation during the testing and installation of the system into the Proton Area.

We wish to express our appreciation to T. O'Halloran and A. Wattenburg of the University of Illinois and J. Peoples of Fermilab for their help in the initial planning and design of the facility.


## References


1. Patent pending.
2. J. M. Brooks and M. A. Otavka, Rev Sci Instr. 39, 1348 (1968).
3. B. Knapp, et al., Phys Rev Ltrs (to be published).


† This paper was presented at the 1975 Particle Accelerator Conference and appears in the Conference proceedings.